

## **P. High-Strength Steel Joining Technologies Project (ASP 070<sup>i</sup>)**

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### **Objective**

The objective of the High-Strength Steel Joining Technologies project team is to provide welding and joining expertise to the Auto/Steel Partnership (A/SP) lightweighting projects to facilitate the increased use of advanced high-strength steels (AHSS). Additional project objectives include augmenting the technical knowledge pertaining to welding of AHSS through applied research and development of industry standards for quality acceptance and weldability testing of AHSS.

### **Approach**

- Anticipate needs of the A/SP lightweighting projects and conduct applied research to address identified technology gaps.
- Determine welding parameters to produce quality welds, then statically and dynamically test welds produced at these parameters to quantify individual weld structural performance (See Figure 1). Tensile shear strength, impact energy and fatigue life are typically evaluated.
- Utilize commercially-available equipment or equipment typically found in existing manufacturing facilities for AHSS feasibility assessments.
- Focus on materials classified as Group 3 and 4 (see Figure 2), as well as specific materials recommended by the A/SP Lightweight Structures Group.

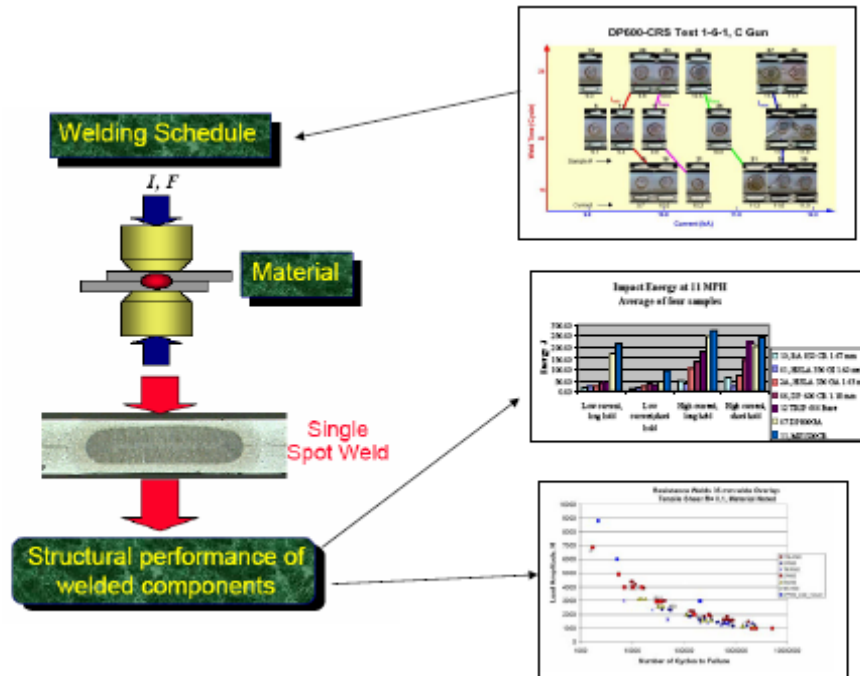
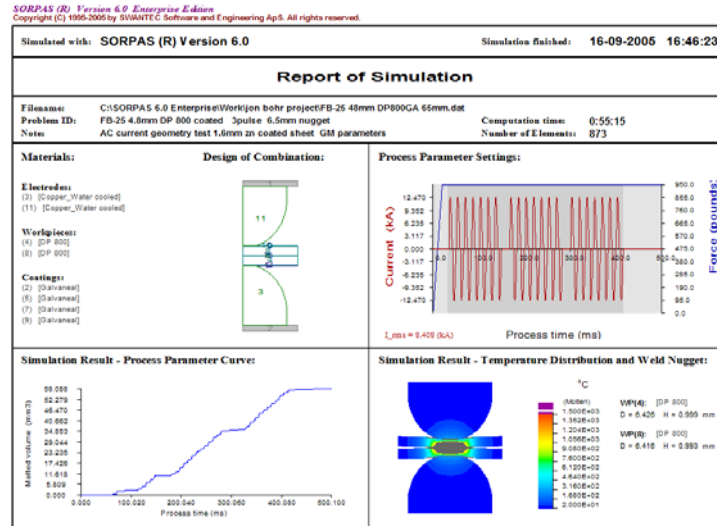


Figure 1. Resistance spot welding.

Group: Tensile Strength (MPa):	1. Low Strength  < 350	2. Intermediate Strength  350 – 500	3. High Strength  > 500 - 800	4. Ultra High Strength  > 800
Typical Materials:	Mild 140YS/270TS BH 180YS/300TS BH 210YS/320TS BH 240YS/340TS	BH 260YS/370TS HSLA 280YS/350TS HSLA 350YS/450TS DP 300YS/500TS	DP 350YS/600TS TRIP 350YS/600TS DP 500YS/800TS TRIP 500YS/800TS CP 700YS/800TS	DP 700YS/1000TS MS950YS/1200TS MS1150YS/1400TS MS 1250YS/1520TS HS 950YS/1300TS
Note: Steels with a minimum tensile strength above 500 MPa (Groups 3 and 4) are generally considered Advanced High Strength Steels (AHSS).				
Source: International Iron and Steel Institute (IISI), <i>Advanced High Strength Steel (AHSS) Application Guidelines</i> , 6 June 2006.				

Figure 2. IISI steel classifications for welding.

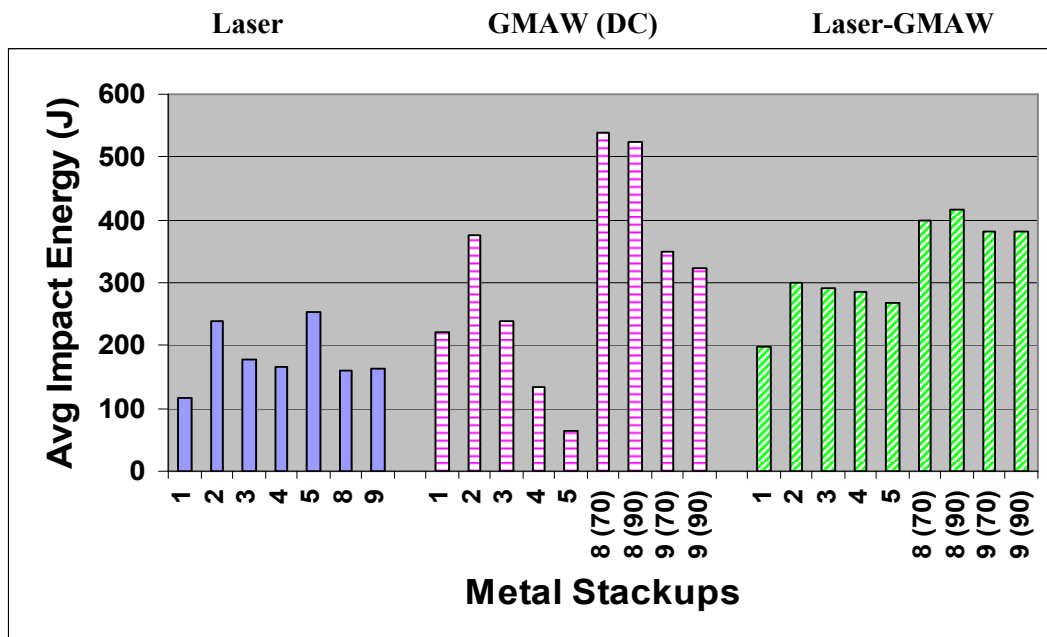
- Investigate the use of process finite-element modeling to predict weld quality characteristics and optimize weld process parameters (See Figure 3). Utilize simulation for future projects to develop weld process optimization and weldability assessments. Validate simulation results with experimental data.



**Figure 3.** Process simulation report for RSW of DP780 utilizing B-nose electrode and 3-pulse weld schedule.

### Recent Accomplishments

- Completed Resistance Welding Project Design of Experiment and report entitled “An Investigation of Resistance Welding Performance of Advanced High-Strength Steels”.
- Completed the test-plan matrix for evaluation of weld processes including MIG, laser-assisted MIG, and plasma-assisted MIG (see Figures 4 and 5). Completed final project report of Structural Weld Sub-Group (SWSG) study.



**Figure 4.** Impact energy comparison.

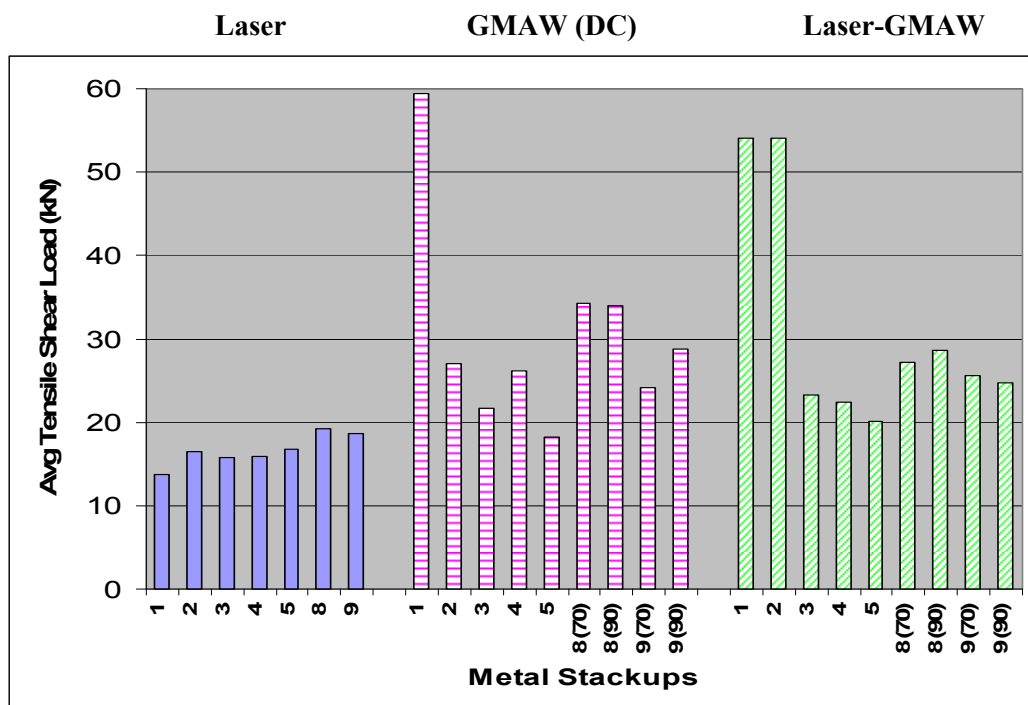


Figure 5. Tensile shear strength comparison.

- Developed weld parameters for specified material grade and thickness combinations for the A/SP Lightweight Rear Chassis Project (see 2.Y), provided technical direction and applied welding practices to fabricate prototype lightweight rear chassis featuring AHSS.
- Produced and tested samples to quantify effect of temperature on impact strength. Completed final project report; "Temperature Effect on Impact Performance of AHSS Welds". Results presented at the AWS Sheet Metal Welding Conference and International Auto Body Congress.
- Completed projection-weld-fastener resistance-weld process and simulation study. Worked with the University of Waterloo to model the projection welding of a hex-flanged weld nut using SORPAS with a cylindrical block model. Weld test results have correlated with the model. Completed final project report; "Assessing Weldability of Projection Welding Fasteners to AHSS Using Finite Element Analysis".
- Provided data and post-test samples of tensile shear and impact tests to support development of an automotive industry AHSS resistance-weld quality standard and provided technical support for development of AHSS fracture classification matrix for the standardization effort. (See Figure 6)
- Provide input and materials to Oak Ridge National Laboratory DOE FreedomCAR project on weldability and performance of AHSS in automotive structures (see 5.C).

**PROPOSED STANDARD FRACTURE CLASSIFICATION**  
**Submitted to AWS D8 Automotive Standards Committee**

WELD FRACTURE CLASSIFICATION							
Fracture Type & Code Number	Weld Fractures - Side View	Weld Fracture Plan View & Code Letter - Bottom Sheet (all may not appear as in side view)					
		A	B	C	D	E	F
		Approximately Round	Approximately Oval	With Hollow Area	Approximately Crescent Shaped	With Irregular Button/Fused Area	With Multiple Button/Fused Area
1 Button Pull - Thru sheet button pulled without any evidence of interfacial fracture							
2 Partial Thickness Fracture + thru sheet button							
3 Partial Thickness Fracture - Weld fractures at point partially thru opposing sheet							
4 Partial Interfacial Fracture + Partial Thickness Fracture + thru sheet button							
5 Partial Interfacial Fracture + thru sheet button							
6 Partial Interfacial Fracture + Partial Thickness Fracture							
7 Full Interfacial Fracture - Interfacial fracture exists without evidence of through sheet button pull or partial thickness fracture				Not Applicable			
8 No Fusion - (No evidence of fused area the vicinity where weld current had passed)				Not Applicable			

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Figure 6. Proposed fracture classification matrix.

### Future Direction

Future team activities include supporting welding development for the A/SP AHSS Application Guidelines Project Team and developing welding parameter and joint performance data for specific applications on AHSS automotive body prototypes. Future project work also includes:

- Publish the results of the completed project to assess the capability to perform drawn-arc stud welding on AHSS.
- Complete development of a design of experiment (DoE) methodology for material characterization and for assessing manufacturing feasibility of spot-welding AHSS.
- Develop software application to support common deployment and analysis of the AHSS Design of Experiment test method.
- Develop arc-weld procedures for various weld filler metals and AHSS joints, including determining the hot cracking susceptibility and filler-metal compatibility of sheet AHSS materials.
- Complete development of set-up or starting resistance spot-weld schedules and publish the results

## **Resistance Spot-Weld Project**

The purpose of this project is to evaluate the weldability of the new advanced high-strength steels (AHSS) currently being considered by the automotive companies as a solution to lightweighting without compromising cost or structural strength.

The issue facing the producers using resistance welding is to determine if interfacial fracture concerns with lower grades of steel are applicable for AHSS materials. Generally, all standards existing as of 1999 are based on welding of mild steels. The diminished performance of welds exhibiting interfacial fracture was generally accepted for steel grades below 420 MPa. Even in the-low strength materials, interfacial fracture is a common mode when welds are made in thick materials and in structures having mechanically stiff sections. These requirements for lower grades may not apply to AHSS grades.

### **Objectives**

The objective of this work was to characterize AHSS weld properties produced using conventional processes. By reporting these data, designers can determine if the characteristics are suitable for use in specific automotive applications and be assured resistance welds can be produced with conventional production equipment.

1. Develop fracture classifications that can be used to grade welds related to their expected performance based on visual observations of destructive in-process checks.
2. Determine if weld-button pull requirements for lower grades of steel are a relevant strength indicator for resistance welds in AHSS.
3. Document and report all the testing equipment characteristics used to produce the test welds.
4. Report the chemistry and physical characteristics of the base metal actually tested.
5. Determine static and dynamic properties and micro-hardness of welds made using conventional welding processes and standard test methods where they exist.
6. Report fatigue characteristics of welds made with conventional weld practices.

## **Project Results**

1. Based on the test data that evaluated resistance welds using traditional production processes, AHSS materials are higher in static tensile shear strength, higher in impact tensile peak load and energy absorption than the baseline HSLA materials used in this study. AHSS are higher in static and dynamic loading gage-for-gage than DQS and other traditional low-carbon steels with yield strength below approximately 400 MPa.
2. Weld lobes were developed for the range of materials studied in this project. The lobes represent a broad range of values that can be used with conventional automotive welding equipment such as robotic welding, manual welding and machine welding processes.
3. Optimum flat sample width was determined for static and dynamic testing of spot welds to reduce the cost of fabricating special formed channels and using special grippers for the test equipment.
4. Using optimum flat sample width, welds were produced representing largest and smallest acceptable weld size and longest and shortest practical hold times.
5. Tensile shear and impact data were obtained for the range of materials and weld parameters studied in this project using a two-level, two-factor experimental design.
6. A fracture classification matrix was established to enable standardized reporting of qualitative data for destructively-tested welds. This classification matrix is in the process of being adopted by AWS/ANSI.
7. Fatigue performance of resistance spot welds was obtained for all the materials in this project. Fatigue testing was performed at two load ratios,  $R=0.1$  and  $R=0.3$ , for all the AHSS materials in this project and compared to base line materials of DQSK, IF, and HSLA. One additional test using full reverse loading ( $R=-1$ ) was performed to demonstrate the effect of load mode and sample width on fatigue life.
8. AHSS resistance-weld effectiveness was confirmed by applying welding processes developed in this investigation to an AHSS lightweight front structure. This confirmation test demonstrated that the AHSS resistance-

welded assembly performed to engineering requirements with no remarkable weld failures.

The project has been completed and the final report written. An Executive Summary PowerPoint presentation has been prepared and presented to the Joining Technologies Team at large, as well as the A/SP Team.

### **SWSG MIG/Laser Project (Structural Welding Subgroup)**

The arc-welding processes have historically been, and are today, commonly used in the manufacture of automotive structures. Recent increased usage of AHSS in automotive designs initiated a need to evaluate the application of arc-welding processes relative to the joining of AHSS.

This project establishes suitable welding parameters for AHSS material iterations (DP600, DP780, DP800, DP980 and HSLA350). Material section thicknesses ranged from 1.0 mm to 3.4 mm. Five arc-welding processes (GMAW-Pulse/AC, GMAW-Pulse/DC, Laser-GMAW, Laser, and Laser-Plasma) were examined in this operation.

Special consideration was given to the acceptance criteria for this project's welds. The standards of the three OEMs were reviewed and a derivative acceptance standard was established for this study. Hardness/metallographic, impact, and yield/tensile properties related to the resulting weldments are presented as the results of this investigation.

- AHSS materials were successfully joined with the processes studied.
- Weld processes utilizing filler material demonstrated better results than processes with no filler material.
- Laser-welded lap joints generally failed in the weld metal, while GMAW fillet joints generally failed in the heat-affected zone.
- Filler material/electrode strength had no direct effect on the weldment strength.
- Material strength and/or thickness gauge had no influence on laser-welded joint strength.
- Zinc-coated materials demonstrated high levels of porosity without a controlled/ engineered gap.

The project has been completed and the final report written. An Executive Summary PowerPoint presentation has been prepared and presented to the Joining Technologies Team at large, as well as the A/SP Team.

### **Lightweight Rear Chassis Structures**

The Rear Chassis team of the Auto/Steel Partnership needed assistance in welding a lightweight design from Dual-Phase 600, 800, and 980 materials. After obtaining the various materials, the Joining Team proceeded to evaluate the weldability of these materials, and to test weld the combinations prescribed for a rear-end structure. The Joining Team established the weld parameters and assisted the prototype source in making the structure. Weld parameters were delivered to the Rear Structures Team along with mechanical and chemical properties of the test materials.

### **Low-Temperature Impact Project**

To date, performance data have only been reported under ambient temperature conditions, and effects of extreme temperatures on impact of resistance spot welding of AHSS steels have not been considered. This study was focused on the impact performance, through impact energy and peak load of various stack-up combinations of AHSS and mild steels at a large range of possible application temperatures. The conducted experiments provide a better understanding of the effects of extreme cold/hot weather conditions of resistance spot-welded joints. The dynamic responses to low- and high-speed impact loading are investigated, which interact with the effects of stack-ups and temperature. The results show that impact energy and peak load are significantly different in magnitude, trend, and scattering/variation. This study also shows that impact energy is more sensitive to material combinations than peak load.

The project has been completed and the final report written. An Executive Summary PowerPoint presentation has been prepared and presented to the Joining Technologies Team at large, as well as the A/SP Team.

### **Assessing Weldability of Projection Welding Fasteners Using FEA**

While Joining Technology effort has been directed towards resistance spot welding (RSW), little focus has been directed toward projection welding of traditional fasteners to AHSS sheet. Weld schedules and expected weld properties of projection-welded joints between fasteners and AHSS sheet are expected to differ from those in traditional material combinations. The highly alloyed chemistry of AHSS and tailored material properties can result in undesirable properties after these materials are welded. Furthermore, the dissimilar-metal combination that is typical of projection welding of fasteners, adds complexity to the issue as a result of different base-metal properties and weld-metal dilution. In this sense, optimization of the weld process may be difficult as it requires an understanding of the effects of process parameters on the properties of the weld and surrounding base metal.

The projection welding process of an M12/1.75/30 hex-flange 3-projection weld nut to 1.2-mm-thick DP780 HDG AHSS sheet has been modeled using SORPAS. The following conclusions have been drawn:

- A cylindrical-block model is best suited to this application. The axisymmetric geometry assumes one projection that encircles the entire nut resulting in a low current density. The rectangular-block model results in excessive deformation in the nut body and requires reinforcement.
- The modeled results show strong correlation with experimental cross-sections.
- Increasing the weld current results in an increase in weld size.
- Increasing the weld force results in a decrease in weld size.
- Increasing the weld time to 4 cycles results in an increase in weld width, but has little effect on weld height.
- Increasing the weld time beyond 4 cycles has no effect on weld size.
- A peak in power during the first 4 cycles due to contact resistance causes rapid melting and collapse of the projection.

- Decreasing current density after collapse limits further nugget growth.
- Increasing the weld time results in an increase in HAZ size, but can also result in lower cooling rates.
- Modeling and experimental results indicate the projection weld nut in this study to be weldable to DP780 HDG sheet material under various conditions.

The project has been completed and the final report written. An Executive Summary PowerPoint presentation has been prepared and presented to the Joining Technologies Team at large, as well as the A/SP Team.

### **Conclusions**

Additional welding issues will be addressed during 2007 by the Joining Technologies Team, funded by USAMP Lightweighting initiatives and member-company in-kind contributions.

### **Presentations and Publications**

1. Warren Peterson, Edison Welding Institute; Ilaria Accorsi, DaimlerChrysler Corporation; Ted Coon, Ford Motor Company; "Review of Weld Mechanical Property Specification Requirements in AWS D8.1 (Proposed);" Presented at the May 9-12, 2006 American Welding Society Sheet Metal Welding Conference XII in Livonia, Michigan.
2. Amir R. Shayan, Xiao Su, and Hongyan Zhang, University of Toledo; Bipin B. Patel, DaimlerChrysler Corporation; "Temperature Effect on Impact Performance of Advanced High-Strength Steel (AHSS) Welds;" Presented at the May 9-12, 2006 American Welding Society Sheet Metal Welding Conference XII in Livonia, Michigan.
3. Michael L. Kuntz, University of Waterloo; John C. Bohr, General Motors Corporation; "Modeling Projection Welding of Fasteners to AHSS Sheet using Finite-Element Method;" "Presented at the May 9-12, 2006 American Welding Society Sheet Metal Welding Conference XII in Livonia, Michigan.



4. James Dolfi, Dolfi AWS, “An Investigation of Resistance Welding Performance of Advanced High-Strength Steels,” Presented at the September 19-21, 2006 International Auto Body Congress in Novi, Michigan.
5. Michael D’Agostin, RoMan Engineering Services, “Advanced High-Strength Steel (AHSS) Weld Performance Study for Autobody Structural Components.” Presented at the September 19-21, 2006 International Auto Body Congress in Novi, Michigan.
6. Bipin B. Patel, DaimlerChrysler Corporation; Amir R. Shayan, Xiao Su, and Hongyan Zhang, University of Toledo; “Impact Testing of Advanced High-Strength Steel (AHSS) Resistance Spot Welds at Various Temperatures,” Presented at the September 19-21, 2006 International Auto Body Congress in Novi, Michigan.
7. John Bonnen, Ford Motor Company, “Fatigue of Spot Welds in Low Carbon, HSLA, and Advanced High-Strength Steels and Fatigue of Fusion Welds in Advanced High-Strength Steels,” Presented at the September 19-21, 2006 International Auto Body Congress in Novi, Michigan.

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<sup>i</sup> Denotes project 070 of the Auto/Steel Partnership (A/SP), the automotive-focus arm of the American Iron and Steel Institute. See [www.a-sp.org](http://www.a-sp.org). The A/SP co-funds projects with DOE through a Cooperative Agreement between DOE and the United States Automotive Materials Partnership (USAMP), one of the formal consortia of the United States Council for Automotive Research (USCAR), set up by the “Big Three” traditionally USA-based automakers to conduct joint pre-competitive research and development. See [www.uscar.org](http://www.uscar.org).